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Endurance of trunk muscles in persons with chronic low back pain: Assessment, performance, training

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Abstract—Trunk muscles are designed to fulfill their role of continuous activity throughout the day, but pain and inactivity alter muscles so that they fatigue in normal situations. Lack of endurance of the trunk muscles is an important factor in low back pain (LBP). This paper examines some methods to objectively test endurance of trunk flexor and extensor muscles in static and dynamic situations, and presents results of endurance testing in persons with chronic LBP compared to nonimpaired cohorts. Self perception of fitness affects some test results. Methods for increasing endurance are discussed along with benefits observed from training programs.

Key words: *fatigue, low back pain, muscle performance, physical exercise.*

INTRODUCTION

The muscles of the trunk are active whether one is sitting, standing, lifting, or rolling over in bed. Adequate endurance of trunk muscles is necessary to good health, and is something taken for granted until the first episode of low back pain (LBP) occurs, an episode said to happen to 80% of the U.S. population at some time in their lives. About half of those individuals will have reoccurrences within the first year of the first episode, leading to a possible history of chronic low back pain (CLBP). This paper examines some methods for testing trunk muscle endurance, some reported values of performance, and the effects of training to increase endurance.

Back fatigue and aching muscles of the back are complaints of people with LBP. Furthermore, lack of endurance of trunk muscles has been identified as a predictor of first-time occurrence of low back trouble in men (1), and as a discriminating factor between those who have had a history of LBP and those who have not (2,3). Endurance is mechanically defined as either the point of isometric fatigue, where the contraction can no longer be maintained at a certain level or as the point of dynamic fatigue, when repetitive work can no longer be sustained at a certain force level (4). Fatigue during a day of repetitive work is expressed by many, but it is difficult to quantify objectively. Although sound individuals can lift up to 85 percent of their maximally predicted loads over

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4 hours with little evidence of fatigue (5), they may still describe fatigue, despite the lack of demonstrated physiological evidence. Tests devised to evaluate the endurance of the trunk extensors and trunk flexors in both static and dynamic contractions produce reliable and valid results in specific populations for short-term testing.

The trunk muscles are physiologically suited to provide low levels of activity for long periods of time. These muscles are physiologically postural muscles, being rich in type I fibers (6), which, uncharacteristically, have larger diameters than the type II fibers (7,8). Although trunk flexor and extensor muscles are physiologically postural muscles, they are active throughout most activities, including quiet standing. Persons with CLBP do not demonstrate more trunk extensor activity during quiet standing than their nonimpaired cohorts, possibly because they stand with a posteriorly displaced center of gravity, which results in less need for trunk extensor activity in maintaining upright posture (9).

Endurance factors must be considered in light of other related variables, such as 1) cardiovascular fitness, 2) muscle force capability, 3) motivation, 4) self-image, and 5) perceptual acuity. Endurance testing of trunk muscles examines the localized capability of the flexor and extensor muscles of the trunk to sustain activity. Cardiovascular endurance governs the ability of the entire body to maintain an activity level. Although bicycle ergometer testing, which indirectly governs VO_{2max}, is not correlated with measures of static trunk endurance (10), general cardiovascular fitness must be adequate for any testing that requires subject effort. Strength (or muscle force capability) is determined in part by the physiologic cross-sectional area of muscle. Submaximal exertion is required for endurance testing, but maximal force output is not and is not highly correlated with endurance times. Motivation is necessary for most human subject testing, although some tests to be described below are believed to be independent of subject effort. Self-perception affects testing: those who perceive themselves to be more active produce higher scores on first-time testing (10,11). Finally, there is an association between muscle endurance and muscle efficiency: skilled movements require less muscle activity and hence produce less fatigue. There is an unresolved question as to whether orthoses, such as corsets and weight belts, have any impact on muscle fatigue (12).

METHODS

Testing Trunk Muscle Endurance

Trunk muscle endurance can be assessed mechanically by timing the ability of a person to hold specific postures or to perform specific movements with or without an external load. Trunk muscle endurance can also be assessed electrically by analyzing the electromyographic (EMG) signal of the neural activity during given postures or movements. The EMG technique is believed to be independent of subject effort, and hence more representative of true capability; its limitations include variability of technique, lack of representativeness of whole muscle, and cost factors.

Static Mechanical Endurance Tests

Examples of static mechanical tests for the trunk flexors and extensors are shown in **Figures 1** and **2**, respectively. The abdominal endurance test requires that a line drawn between the crests of the ilia remain visible for as long as the subject can hold the position (13). Hyytiainen reports the reproducibility is good ($r=0.90$), but that the testing is time-consuming. The trunk extensor endurance test, in which the subject's upper body is suspended in a prone position with arms at sides is known as the modified Sorensen test position. The reliability in sound subjects is good, but in persons with CLBP, the repeatability is high ($ICC=0.96$) only for subjects who consider themselves to be active, and low ($ICC=0.39$) for those who believe themselves to be inactive (10).

The torque generated by the trunk extensor muscles during the Sorensen Test has been reported by Smidt and Blanpied to approximate 52 percent of maximal voluntary capacity (MVC) of their capability (14); however, Holmstrom, using a scale to weigh the upper torso and a rule to measure the moment arm, reported that subjects only created a torque equal to 40 percent MVC in this testing (3). The hip extensor muscles contribute to maintaining the suspended prone posture, but their proportionate contribution has not been reported. The torque generated by the upper body in the static abdominal endurance test has not been reported, but it is significantly less than for the extensor testing because of the reduced moment arm. Furthermore, the abdominal muscles are aided by the hip flexor muscles, which act directly on the lumbar spine, whereas the hip extensors do not. These comparative torque calculations suggest that the abdominal muscles create less torque in endurance test-

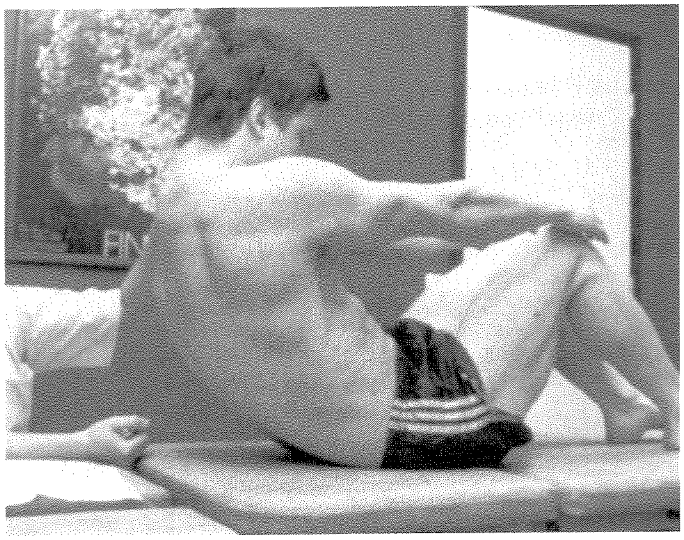

Figure 1.
Example of position to test endurance of abdominal muscles. (Reprinted with permission of the *Scandinavian Journal of Rehabilitation Medicine* and Kristiana Hyytiainen, PhD, MD.)

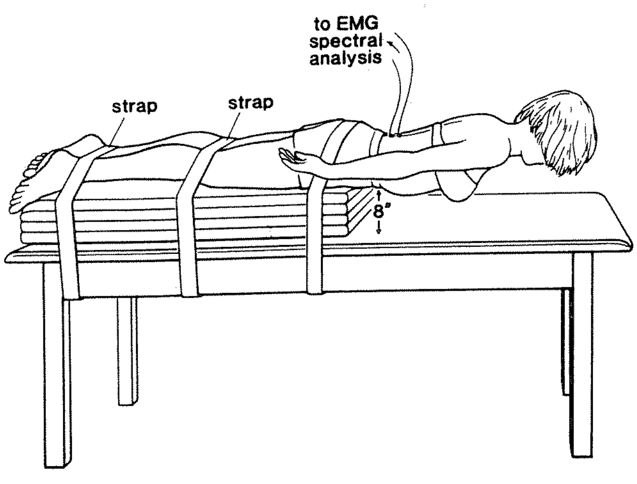

Figure 2.
Example of position to test endurance of trunk extensor muscles. (Reprinted from *Physical Therapy,* Moffroid MT et al. Endurance Training of Trunk Extensor Muscles. 1993:73(3):3–10, with the permission of the APTA.)

ing than do the trunk extensors. Whether or not these biomechanical differences are balanced by the fact that the trunk flexors are weaker than the extensors is an open question (15). Some investigators test abdominal muscle endurance in the curled position with only the scapulae clearing the table (3,16). In such instances, the torque is greater because of the longer lever arm. The hip flexors have a less favorable angle of pull, and the abdominal muscles are more lengthened, which also contribute to a more challenging test for abdominal muscle endurance. Muscle torque production does not correlate highly with muscle endurance (3), but adequate torque must be created to assume the test position. Muscle fatigue is related to the number of actin-myosin cross-bridge interactions, and the susceptibility of muscle to fatigue is decreased in shortened positions where cross-bridge interactions are more numerous (17).

Changes in test position affect which portions of the trunk muscles predominate in activity. Roy et al. have shown lower lumbar portions of the back extensors to be more susceptible to fatigue than the upper lumbar portions (18), a finding that may reflect the longer moment arm, and hence increased torque production. However, morphological studies have shown that there is an increase in the percentage of fast twitch fibers from the thoracic to the lower lumbar extensor muscles (19), a finding that is consistent with a higher propensity for fatigue in the more caudal muscles.

Dynamic Mechanical Endurance Tests

Dynamic mechanical endurance tests have more face validity because they more closely simulate functional activities, and they have more discriminant validity, since those with previous LBP demonstrate greater losses in dynamic tests than in static tests, compared to persons with no previous LBP (4). Motion testing adds variables of velocity and direction, so that the measurements become more complex. Trunk rotation and lateral bending increase as fatigue develops during repeated sagittal trunk movements against a fixed load (20), and the velocity of lateral trunk motion in job requirements may predict worksite injury (21).

Isokinetic dynamometers produce reliable data about trunk endurance in persons with CLBP (22), but the transference of results to a work or home situation is weak, since individuals work and play using a variety of concentric and eccentric muscle contractions during varied velocities of motion.

Dynamic endurance has been tested for concentric and eccentric muscle activity. Standardized testing requires that repetitions be quantified, usually to some percentage of MVC. There is little confidence in what the MVC of a person is if testing is done during an episode of back pain (23), so testing at a calculated percentage of a questionable amount will produce spurious data. There is no surprise that persons with CLBP produce less integrated EMG signals (iEMG) than control subjects, because the loads they are required to sustain in endurance testing are much less (24).

Rissanen et al. also explored noninstrumented dynamic repetitive testing of both the trunk flexors and the trunk extensors in persons with CLBP using repetitive curlups and archups. They reported modest correlations with pain, disability, and instrumented testing and concluded noninstrumented testing was a clinically viable alternative (22).

EMG Endurance Testing

The electromyogram recorded from submaximal voluntary muscle activity changes with muscle fatigue. The iEMG activity will increase over time because of additional recruitment and synchronization of motor units, provided the torque level is sustained (25). If, on the other hand, exercise is taken to exhaustion and the torque levels decline, then the iEMG will decline over time.

The median frequency (MF) of the EMG power spectrum declines with localized muscle fatigue, in such a way that the slope of the change of the MF can be used to characterize fatigue (**Figure 3**). The slope of the lumbar extensor muscles is linear (26), and has been shown to be reliable in test-retest situations of short-term (27) and long-term (3 mo) periods (28). Slope measures are not as repeatable as recording the initial frequency measures (IMF) once a minute (for 5 s) until recovery (29).

The MF decline is related to physiologic events of slowing fiber conduction due to metabolic changes during localized muscle fatigue, hence it is independent of voluntary effort, although not all of the variance can be accounted for by fiber conduction velocity changes (30). The IMF measure varies with several factors, making long-term reliability measures questionable. Closer-spaced or smaller electrodes, decreased skin resistance, less subcutaneous tissue, or higher levels of effort will produce higher IMFs.

In order for the MF measures to be standardized, the physical task must be controlled. Some investigators have used the modified Sorensen Test position with (31), or without (10), an added load, an arm-hold task in the standing position (27), or a trunk extension effort in standing requiring 80 percent MVC (18). In a small group of subjects without back pain, the MF decline of the longissimus and multifidus muscles at L3 was obtained from recordings of intramuscular wire electrodes (32). In the standing position, the longissimus demonstrated a steeper slope, indicating more fatigue (**Figure 4**), but in a forward bend position with a load in the arms, the multifidus demonstrated an increased slope of MF decline compared to the longissimus at that same vertebral level. Clearly the static posture (erect or bent) affects muscle activity.

The EMG measures hold promise for assessing localized muscle fatigue. Current concerns are the need for sophisticated hardware and software, a lack of full understanding as to why the MF declines, and the need for evoking efforts approaching 50 percent MVC to obtain a decline in the MF. The latter condition makes onsite monitoring in a workplace impractical, since most work occurs at a much lower effort throughout the work day, and muscle activity is intermittent, not static.

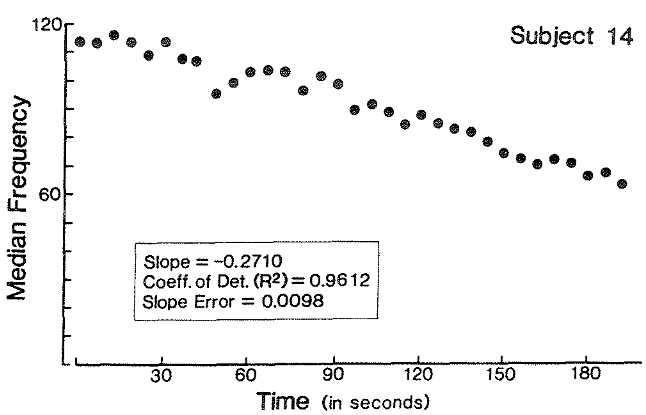

Figure 3.
Change in MF during a Sørensen Test. The slope indicates muscle fatigue. (Reprinted from *Physical Therapy,* Moffroid MT et al. Endurance Training of Trunk Extensor Muscles. 1993:73(3):3–10, with the permission of the APTA.)

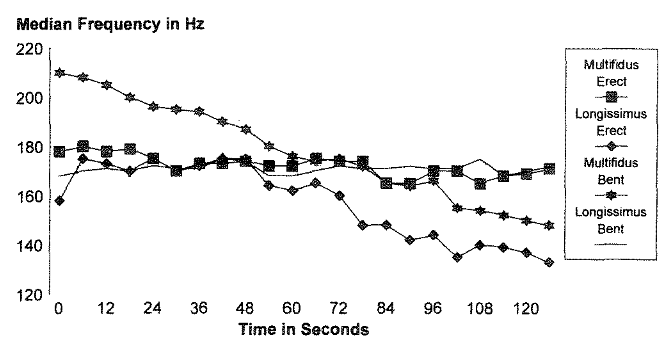

Figure 4.
Comparison of the decline in MF between the Longissimus and Multifidus muscles at L3 vertebral level.

EMG testing for endurance can be used with dynamic or static contractions, but the latter is more useful because EMG measures are confounded by the effects of muscle length changes and accelerations and decelerations in movement. Under dynamic conditions, the EMG signals are not stationary, and cross terms are introduced during signal processing, which lead to spurious MF results. Another technique known as the Modified Wigner Ville has been described, which purportedly circumvents these problems, but the technique is still in the development stage and has only been tested by computer modeling (33).

Whether one is assessing amplitude (iEMG) or frequency (decline of MF), adequate sampling of active muscles is important, and extremely difficult to achieve with the complex, layered muscles of the trunk. Increasing the number of electrodes, and including intramuscular sites, increases the representativeness of the data.

Test Performance of Persons with CLBP

Persons with CLBP demonstrate reduced endurance of trunk flexor and extensor muscles. Investigators have reported endurance measures of persons, sometimes compared to control groups without LBP. Differences have been noted, but no longitudinal studies have been performed to determine causal relationships. Clinical studies often involve few subjects on whom many measurements are made. Reported statistically significant differences may occur by chance alone, or important results may go unreported because of low statistical power in too-small samples. Endurance measures in persons with CLBP have never been reported according to any classification system of subjects. Because persons with LBP have been classified by signs and symptoms (34), postural characteristics (35), and pain patterns (36), variables such as age, gender, muscle length, and motivation may confound the data in heterogeneous samples.

Mechanical Endurance Test Performance of Persons with CLBP

Static endurance is decreased in persons with CLBP. Holmstrom et al. assessed construction workers with and without LBP and reported significant differences in their endurance times based on LBP history, independent of smoking habits or physical activity (3). Moffroid et al. also examined static holding times in the Modified Sorensen Test for persons with CLBP and also reported little effect due to smoking or physical activity, weak correlations with bicycle ergometer testing, and positive correlations with the decline of the MF in both the lumbar extensors and the biceps femoris (10). The modified Sorensen Test position produced more fatigue, as measured by the decline of the MF, in the biceps femoris than in the paraspinal muscles at L3, suggesting that this test challenges the hip extensors more than the trunk extensors. The authors found that all measures were repeatable, but only for persons who considered themselves fit. Knapik examined the validity of self-assessed physical fitness and reported that only the fit were capable of accurately prejudging performance measures (11). Taking the two studies together, one might conclude that unfit populations might be better at self-assessing, given opportunities for repeat testing.

Hultman et al. studied 3 groups of middle-aged men: 36 with nonimpaired low backs, 91 with intermittent LBP and 21 with CLBP (37). The nonimpaired group had longer trunk muscle endurance times, yet in all 3 groups the ratio of trunk extensor endurance to trunk flexor endurance approximated 3:1. Endurance of both trunk flexors and extensors is also decreased in 15-year-olds with back pain histories compared to those free of back pain (2). In contrast to findings in middle-aged men, the adolescent population of boys and girls held the trunk extension test about 20 s longer, probably because subjects were lighter, and were asked to maintain a suspended prone position with fixation of the iliac crests (2), compared to fixation of the anterior superior iliac spine (37), resulting in a shorter lever arm and less torque. The adolescents also had longer trunk flexor endurance times (nearly 3 times as long as those reported for the middle-aged men). The reduced flexor endurance time of the middle-aged men, compared to that of the adolescents, may have resulted from changes with aging as well as differences in body mass and body proportions (4). Adolescents have an advantage in trunk curl activities because their trunks are proportionately short compared to their lower limbs (38). Longitudinal studies are needed to provide answers to these suppositions.

As has been noted, dynamic repetitive testing reveals larger decrements in endurance than static testing in persons with CLBP, but both are reduced in male and female workers with reported histories of LBP (4). Acknowledging that those with back pain or histories of back pain may be less active, and may perceive themselves to be less active, one has to question studies that draw conclusions about test differences from single tests that demand maximal effort from subjects. Noninvasive

EMG testing provides additional data for testing that does not demand maximal effort.

EMG Endurance Testing Performance of Persons with CLBP

EMG amplitude is an indication of motor unit recruitment and also of signal amplification, skin resistance, distance of the recording electrodes from the active muscles, muscle activity, and electrode size. Tsuboi reported that their 9 subjects with LBP had significantly greater iEMG when holding a prone posture with added weight equivalent to 30 percent of MVC than did 10 subjects with unimpaired backs (31). Because the MVC values for the subjects were lower than for the controls, the authors interpreted the findings to mean that more of the inefficient Type II fibers were being recruited in the subjects with LBP, producing larger amplitudes of iEMG. Other interpretations are plausible: with no normalization of iEMG to MCV, no conclusions can be drawn; with no normalization of body mass (which affects the torque in the suspended prone test posture), no conclusions can be drawn; or one might consider that atrophy of muscles in subjects with CLBP, as described by Hultman et al. (37), require more motor units to be fired in order to achieve desired force levels. Robinson, also studying iEMG in those with and without CLBP, reported that those with CLBP achieved higher MVC levels, were tested with more weight, yet demonstrated less iEMG during dynamic repetitions of flexion and extension (24). They argued that this supported a muscle deficiency model, but given the higher levels of test loading, one has to wonder about movement strategies and substitution of other muscles not being recorded.

MF shifts are commonly reported representations of EMG recordings in fatigue studies of persons with CLBP. As expected, authors have uniformly reported that persons with CLBP demonstrate steeper declines of MF compared to controls (13,29,31).

Given the paucity of data, the variability of the populations studied, and the small sample sizes, one can only project that the data collected to date suggest that EMG measures of endurance hold promise, and that there are significant differences between those who have present or past history of LBP.

Right-left measures of the decline of the MF in paraspinal muscles during isometric extension testing do not show consistent patterns of symmetry or asymmetry. Whereas some authors find that persons with CLBP show more asymmetry (24), others have shown none (39), or inconsistent patterns (10,31). The failure of investigators to classify subjects prior to testing may preclude identifying consistent patterns of symmetry or asymmetry during fatiguing contractions.

Perceptual Differences Related to Endurance Testing in Persons with CLBP

Measures of balance and postural control include measures of motor efficiency. Assumptions are that if postural control is not efficient, muscle activity is unnecessarily ongoing and leads to fatigue and, hypothetically, to injury. A few investigators have examined postural control in persons with CLBP and have reported a more posteriorly displaced center of gravity and a higher velocity kinetic displacement during a backward perturbation (9), increased psychomotor reaction time and decreased movement time (40), and inefficient work postures (41). The study of postural control and motor control parameters is still in its infancy, particularly as related to persons with CLBP. Some of the measures of postural control may provide information about muscle recruitment and use or overuse that result in fatigue and musculoskeletal injury.

Training to Increase Endurance

Muscles respond to loading in many ways, including becoming more endurant. Trunk muscle endurance can be increased by exercises for static loading (26), graded activity programs (16), and leisure activities (42). Specificity of training applies to endurance training as much as to strength training. Research to determine how endurance training of trunk muscles in persons with CLBP affects performance and function is sparse.

Moffroid et al. described a series of exercises that increased static mechanical endurance of trunk extensors in sound women over 6 weeks but did not significantly alter the MF measure, either because the measure was not sensitive enough or because physiologic changes did not occur (26). Thompson reported changes in both static holding time and in MF measures in a sample of middle-aged women with CLBP after 12 weeks of exercise (28). Exercises that are repetitive and focused may not equate to improved motor function. Exercises must be goal-directed, and in keeping with what we now know about motor control: at least some of the environmental conditions of noise, lighting, uneven floor surfaces, and unexpected interruptions should be normal components of the exercises. Certain features of the environment are essential to the improvement of skill within tasks. The context helps organize the system to best accomplish the task. Qualitative changes in posture and movement can occur dramatically and spontaneously as a result of gradual changes in parameters of strength, endurance, range of motion, movement velocity, and recruitment strategies. Exercises to improve strength, endurance, range of motion, movement velocity, and recruitment strategies must take place within the context and environment relevant to function, or motor learning will not occur. Exercise and motor learning are not synonymous.

Research studies in which endurance exercises have been one component of a varied program demonstrate positive outcomes in measures of reduced work loss (16,43,44). Lindstrom incorporated graduated mobility and fitness training over 1 year and noted improved return-to-work rates in the experimental group, as well as significantly improved abdominal trunk endurance (measured statically) and lifting capacity (16). Gundewall et al. followed two groups of workers with back pain complaints, allowing subjects in one of the groups (N=30) to perform a variety of exercises, some of which addressed dynamic endurance training of the trunk extensor muscles (43). After 13 months, the authors reported that the experimental group reported significantly decreased back pain intensity, and had significantly fewer work-loss days due to back pain ($p<0.004$). LeFort et al. provided a combination of water-based aerobic exercises with isotonic loading for all major muscle groups, including the trunk flexors and extensors, for 8 weeks. A retrospective analysis showed that all subjects (N=40) improved significantly in measures of physical fitness (pulse rate and weight lifted), but those subjects who did not demonstrate improvements in pain or disability (Oswestry Scale) had lower return-to-work rates, lower self-esteem, and histories of previous low-back incidents (44). Improvement of physical parameters, such as strength, cardiovascular fitness, and endurance, was a necessary but not sufficient ingredient for return to work. Other variables proved more critical, especially stability of self-esteem and case of a first-time injury.

Salminen, retrospectively studying 15-year-olds with and without back pain, concluded that those children who participated regularly in leisure time physical activities (twice a week or more) demonstrated increased spinal mobility, greater endurance of back muscles (modified Sorensen testing), more dynamic strength of the trunk flexors (sit-up testing), and reported significantly less LBP (42). Relational studies, such as this one, cannot prove cause and effect, but taking the information from all of the retrospective and intervention studies together, one can formulate a hypothesis that goal-directed activities that incorporate specific muscle actions in a variety of ways, performed over many months, will positively affect endurance performance and function.

CONCLUSION

This paper has described measures of trunk flexor and trunk extensor endurance, specifically as they relate to persons with chronic LBP. Decreased endurance has been noted as a predictor of first-time occurrence of LBP, and also as a finding in persons with CLBP compared to those with sound backs. Training has been shown to improve measured endurance characteristics of the trunk muscles, but diverse intervention programs over several months duration appear to be the most successful in improving physical performance. Return to work and other functional outcome measures depend not only on trunk muscle endurance and other physical attributes, but also on previous injury history and self-esteem.

The challenge in addressing decreased trunk endurance is to apply our knowledge and skills to design exercise programs that still incorporate principles of kinesiology, biomechanics, neuroscience, physiology, motor learning, and psychology–but within the context of the environment, personal goals, and societal demands.

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